A NOTE ON THE WINDS

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August 1977

ABSTRACT

Winds play an important part in our lives. This paper presents a few of the problems in wind measurement and discusses the problem of standardization in general. Specifically, the standardization to a common pre-selected level is discussed so that applications to extreme wind conditions can be examined. The consensus is that until more is known about the wind structure for the extreme conditions of the hurricane, tornado, squall line, chinook, the observed, recorded and edited wind data need not be modified to a standard height level. The extreme winds observed should be used directly without change for any heights within the layer.

INTRODUCTION

Winds always have and always will play an important part in life on earth. Book after book, article after article, and theme after theme present facets of this phenomenon. Yet there still remains much to be learned. There is a need to know more from an energy viewpoint, i.e., energy that can safely be used to advantage and energy in forms that are dangerous.

MEASUREMENT OF WIND

1. Instrumentation

Qualitatively, for a long time much has been known about wind from the barest motion above molecular or diffusion stages to the catastrophic winds of the great storms. Quantitatively, the wind, among other uses, was used in wind powered mills, in ventilation, and in wind powered ships. The Beaufort wind scale was designed to put some quantitative measure to the wind. Ships built and calibrated to the Beaufort scale illustrate the use of essentially probes or instruments utilizing sails and airfoils of great size.

In another aspect of the problem, probes are now more often designed as point probes in an effort to study the structure of the wind in scales downward to the microscale. Wind tunnels have been built to study air flow from low speeds through the hypersonic regions.

But still with all this, there is no international consensus on standards of wind measurement, i.e., anemometry. There is no national standard within the United States of America. Thus, the accuracy and precision of the instruments remain a problem. The American Society for Testing and Materials, in its Committee on Sampling of the Atmosphere, is attacking the problem of meteorological instrumentation standards. Anemometry is only one part.

Therefore, until pertinent standards are available and all manufacturers adhere to those standards, the necessary calibrations are available and fundamentally good maintenance and calibration programs are existent, the accuracy and precision of the recorded winds remain a problem. Only the manufacturers specifications and/or the specifications provided to the manufacturer by the purchaser permit some approach to good records. Even with the best of maintenance programs, problems remain.

2. Exposure

Here, the discussion is general. There are instructions in manuals for the exposure of wind instruments so that measurements of the true wind compatible with the instrumentation accuracy and precision (if known) may be obtained. Topography, obstructions, weather systems, and other features influence the response of the instruments. Under some conditions, flow at low wind speeds is quite different from flow at high wind speeds for there may be layers exhibiting winds of differing directions and speeds. Under such conditions, the wind can only be called a point wind and not representative of any larger region.

In an installation with a single instrument or with a battery of wind instruments on a tower, the probe(s) is(are) influenced by the windward damming of the winds with the tower whether solid or not acting as the obstruction. The recovery of the winds around and over the tower results in winds stronger than the mean air flow. In the lee of the tower, wake turbulence from vortex shedding and the existence of stagnation points both fore and aft of the tower create problems. The instrumentation generally remains fixed, while the troublesome singularities in the wind flow depend on the flow and move about with any change of flow.

3. Change of Wind with Height

In general, within the boundary layer, due to the friction with the earth's surface, the wind is generally considered to increase with increasing height. Some general rules for this variation of the wind with height have been formulated. Hellman (1916) in measurements with tower instrumentation provided some such rules. In such an argument

$$\frac{v}{v_o} = \left(\frac{z}{z_o}\right)^{1/n} \tag{1a}$$

or

$$v = v_o \left(\frac{z}{z_o}\right)^{1/n} \tag{1b}$$

where v_o and z_o are the wind speed and height of the lower level and v and z are wind speed and height at some upper level. The exponent (1/n) or p completes the model for the relationship. The exponent (1/n) is often used as (1/7) and equation 1a is often referred to as the one-seventh power law. Now, this one-seventh simply represents the highest frequency of various powers in Hellman's experiments. Other powers existed and represented differing conditions. In other words, with no further information available, one-seventh is a best guess solution to any particular case.

Davenport (1960) refined this technique to include various values depending on the characteristics of the upwind fetch. His studies indicated that values as high as one-third should be used in highly urbanized areas but again prefers one-seventh for flat, unobstructed areas regardless of wind speed.

But this represents, in general, a relatively stable configuration of conditions, obeying the premise that the wind does increase upwards with elevation.

Table 1(a) taken from Table 99 of Moses and Bogner (1967) clearly shows the distribution of the ratio (1/n) or p derived from data measured on meteorological towers at the Argonne National Laboratory, Argonne, IL. Table 1(a) provides data for p for the 19- and 75-foot levels arrayed against the 19-foot level winds. The months of July and November are selected here. The period of record is 1961-64. Table 1(b) is a similar presentation but contains all observations over all months of the period, January 1961 - December 1964. The two tables show that at Argonne, though the exponent (1/7) or .14 is quite evident, the exponent .11 is equally as important and that some of the other exponents are almost equally important.

Table 2, taken from Table 100 of Moses and Bogner (1967), presents another look at the problem. A comparison is made of the power exponents for the 19- and 75-foot layer and the 19- and 150-foot layer. Some consistency should be noted because of the inclusion of the lower layer in the total layer. The difference of the power exponents, if they were the same in the two layers, should be zero. Fifty-six percent of the cases exhibit a zero difference, while thirty-three percent show a difference of plus or minus .1. This table indicates that in forty-four percent of the cases the power exponent changed .1 or more.

A closer look at the November data and the annual data indicate that for wind speeds greater than 24 mph (11 mps) the power exponents are equally divided between $\leq$ .11 and $\geq$ .14. This feature will be examined in other data presentations.

Singer and Nagle (1962) investigated the variation of p with wind speed at the Brookhaven National Laboratory and concluded that for speeds greater that 14 knots and less than 22 knots, p remained between .20 and .25 for all levels on the tower.

4. Extreme Winds

Extreme wind distribution functions have been used to obtain some idea as to the probabilities associated with specified wind speeds at various locations. Gumbel (1958), Lieblein (1954, 1974a, 1974b), and Gumbel and Lieblein (1954) have developed the usable and practical models. Work continues on the applicability of these and other models (Simiu et al., 1975). Thom (1954, 1960, 1968) has used these models to produce isopleth charts of the United States for the return periods associated with certain return periods. These were based on short periods. Work now underway at the National Climatic Center will, in time, provide a more extensive data base in both space and time. The accuracy and precision of such charts are highly dependent on the space and time coverage.

In the procedure outlined by Lieblein, a set of extreme data of samples size N will have a cumulative probability distribution function of the form

$$F(x) = F(x;\mu,\beta) = \exp\left[-e^{-\left(\frac{x-\mu}{\beta}\right)}\right] \qquad (2)$$

where F(x) is the probability that an observation will be less than a specified value x, μ is the mode of the distribution, and β is the scale parameter. The reduced variate y (analogous to the standardized variate "t" of the Student distribution) bears the following relationship to x, μ, and β:

$$y = \frac{x-\mu}{\beta} \qquad (3)$$

The conversion of y to any desired probability level (P) can be accomplished using the equation

$$P = -\log\,(-\log\,(y_p)) \qquad (4)$$

Estimation and prediction of extreme values for given probabilities can be obtained from the relationship

$$\xi_p = \mu + \beta y_p$$

where ξ_p is the estimated extreme value at the probability level P and y_p is the corresponding reduced variate. Estimates of μ and β can be obtained using numerical methods described by Lieblein (1974b) and Thom (1960).

5. Peak Wind Distribution

Fichtl et al. (1970) studied the peak winds at Cape Kennedy, Florida, in October. Figure 1, modified from that study with permission, shows some important relationships. Fichtl et al. (1970) states, "Thus, for a given percentile level of occurrence, it was found that, for peak wind speeds at the 18-meter level less than approximately 2 $msec^{-1}$, K is equal to a constant, while for peak wind speeds greater than 2 $msec^{-1}$

$$K = bu_{18}^{-3/4}$$

where b is a parameter that is distributed normally with mean value K and variance equal to .52 and .36, and u_{18} is in meters per second." Here, K = (1/n) = p. Figure 2, modified from Fichtl et al. (1970) with permission shows the steady decrease of p at 2 $msec^{-1}$ (4 kts) from almost .3 to .03 at about 45 $msec^{-1}$ (87 kts) and to an extrapolated value of .01 at about 175 $msec^{-1}$ (340 kts). This extrapolation of the model indicates the tendency of the exponent to decrease with increasing speed so that it itself is not constant. The extrapolation is based on few data at the high wind speed so it is beset with some doubt. Nevertheless, the tendency is there and the question is really, how much is the decrease? The last two curves present the inclusion and exclusion of hurricane winds. The values above 41 $msec^{-1}$ peak winds are simple extrapolations of the models.

Sissenwine et al. (1973) also demonstrated the decrease of p with increasing speeds by utilizing a small set of gust measurements from the Argonne tower. They state that "the limiting p value approaches 0.077 as v_{19} (mph) becomes very large." This set was also hampered by a lack of data at the high (>50 knot) speeds.

Tower data were obtained from the National Severe Storms Laboratory's instrumented facility near Oklahoma City and a North Dakota State University facility at Dunn Center, ND. Both towers are located in rolling, open countryside with no significant obstructions to the flow of the wind. The Oklahoma data consisted of readings at 10-second intervals, while the

North Dakota data were 30-minute "eyeball" averages obtained from autographic records. For both locations the data were chosen from selected high wind cases. The data from Oklahoma were processed in 3 sets since the reporting levels changed during the period requested. Set 1, with ~3700 readings (from the 26 m and 45 m levels) contains data for 10 thunderstorm episodes during 1971 and 1972. Set 2, with ~5300 readings from the 89 m and 266 m levels, contains data for 10 additional thunderstorm episodes in 1973, 1974, and 1975. Set 3, with ~5100 readings from the 7 m and 26 m levels, contains data for 2 severe extratropical cyclone episodes in March 1977. The North Dakota data, Set 4, consists of 30-minute averages for 32 high wind speed episodes in 1975 and 1976 with ~900 observations at the 10 m and 50 m levels. Calculated values of p for each case are presented in Figures 3, 4, 5, and 6 for Sets 1, 2, 3, and 4, respectively. These data are retained at the NCC and are not included here. In each figure the calculated p is plotted against the wind speed at the lower of the two levels.

The somewhat different pattern appearing in Figure 3 from that in Figures 4 and 5 is the result of a large number of low wind speeds not occurring in the cases chosen for depiction in Figures 4 and 5. Furthermore, the obvious striations appearing in Figure 3 are the result of the values to which the observed speeds are rounded. This problem of preferred speeds is also apparent in Figure 6.

These figures do corroborate the findings of other investigators of the tendency for observations to centrally cluster around a p value of 0.1 to

0.2. However, they also depict the steady decrease of the mean p and upper boundary of the range of p as wind speed increases. An obvious conclusion one can draw from the figures is a lack of data supporting the use of the p value of one-seventh at high wind speeds. The use of such a value in correcting severe winds to a standard height may lead to a serious underestimate of a true design value.

For some of these sets, at the highest wind speed, the mean value of p appears to be negative, indicating a large number of occurrences of wind actually decreasing with height. This feature is clearly demonstrated by the many negative p values which are plotted in the lower portion of the figures.

The inference by the authors is that with higher wind speeds than those shown here and by other investigators, p should be very close to zero. This implies that for extreme winds no correction to a standard level should be made.

6. Conclusion

In previous studies, p has been shown to decrease with increasing wind speed to a value as low as .07. This value results in significantly less reduction in the wind, especially at high wind speeds, than the .14 (1/7) currently used. Data obtained by the authors has demonstrated that p at the highest wind speeds observed approaches zero and thus no correction to observed values should be made in correcting observations to a standard level.

Acknowledgments

The authors wish to thank Mr. Craig Goff at the National Severe Storms Laboratory, and Dr. Juanito Ramirez and Mr. Timothy Method of the North Dakota State University for their help in providing the data utilized in this paper.

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Table 1a. Joint Percentage Frequency Distribution of P values. Based on 19- and 75-foot wind speeds (mph) and 19-foot wind speed (mph). July and November 1961–1964. (Taken from Moses and Bognar (1967)).

JULY
NUMBER OF OBSERVATIONS 2976

P-VALUES	19-FOOT SPEED (MPH) 1 - 3	4 - 7	8 - 12	13 - 24	> 24	MISSING	TOTAL
0.035	1.48	0.48	0.07	0.03	0.00	0.24	2.65
0.05	0.40	2.08	0.67	0.07	0.00	0.00	3.23
0.08	0.64	4.03	2.45	0.44	0.00	0.00	7.56
0.11	0.77	5.61	5.71	0.64	0.00	0.00	12.74
0.14	0.60	4.54	5.17	1.14	0.00	0.00	11.46
0.17	0.81	3.86	3.66	0.34	0.00	0.00	8.67
0.20	0.57	4.30	2.05	0.07	0.00	0.00	6.99
0.25	1.44	8.67	0.71	0.10	0.00	0.00	10.92
0.33	3.46	7.90	0.07	0.00	0.00	0.03	11.46
0.45	8.10	4.30	0.00	0.00	0.00	0.33	12.53
0.60	4.10	0.13	0.00	0.00	0.00	0.00	4.23
0.676	2.55	0.00	0.00	0.00	0.00	1.68	4.23
MISSING	0.07	0.00	0.00	0.00	0.00	3.26	3.33
TOTAL	25.00	46.27	20.56	2.82	0.00	5.34	100.00

NOVEMBER
NUMBER OF OBSERVATIONS 2880

P-VALUES	19-FOOT SPEED (MPH) 1 - 3	4 - 7	8 - 12	13 - 24	> 24	MISSING	TOTAL
0.035	0.42	0.73	0.14	0.14	0.00	0.07	1.49
0.05	0.24	1.32	0.87	0.38	0.00	0.00	2.81
0.08	0.17	2.26	2.64	0.87	0.03	0.00	5.97
0.11	0.49	2.88	5.45	4.31	0.07	0.00	13.19
0.14	0.49	2.60	5.56	5.31	0.17	0.00	14.13
0.17	0.28	3.09	4.69	2.22	0.00	0.00	10.28
0.20	0.45	2.78	2.85	0.63	0.03	0.03	6.77
0.25	1.28	6.56	2.22	0.10	0.00	0.00	10.17
0.33	2.47	7.53	0.07	0.00	0.00	0.00	10.07
0.45	4.97	4.06	0.00	0.00	0.00	0.00	9.03
0.60	2.78	0.28	0.00	0.00	0.00	0.07	3.13
0.676	1.70	0.00	0.00	0.00	0.00	1.08	2.78
MISSING	1.08	3.61	2.81	0.69	0.00	1.98	10.17
TOTAL	16.81	37.71	27.29	14.65	0.31	3.23	100.00

Table 1b. Joint Percentage Frequency Distribution of P-values. Based on 19- and 75-foot wind speeds (mph) and 19-foot wind speed (mph). January 1961 – December 1964. (Taken from Moses and Bognar (1967)).

ALL YEARS
NUMBER OF OBSERVATIONS 35064

	19-FOOT SPEED (MPH)						
P-VALUES	1 - 3	4 - 7	8 - 12	13 - 24	> 24	MISSING	TOTAL
0.035	0.81	0.81	0.24	0.06	0.00	0.12	2.04
0.05	0.27	1.53	0.98	0.35	0.00	0.00	3.12
0.08	0.33	2.88	3.55	1.66	0.02	0.00	8.44
0.11	0.46	3.78	6.25	3.99	0.09	0.00	14.56
0.14	0.39	3.39	6.46	3.97	0.09	0.00	14.29
0.17	0.46	3.13	4.79	1.77	0.01	0.00	10.15
0.20	0.45	3.03	2.82	0.59	0.01	0.01	6.91
0.25	1.06	6.77	2.21	0.13	0.00	0.00	10.17
0.33	2.05	7.16	0.17	0.00	0.00	0.01	9.39
0.45	4.68	3.97	0.00	0.00	0.00	0.04	8.69
0.60	2.98	0.19	0.00	0.00	0.00	0.01	3.18
0.676	1.97	0.00	0.00	0.00	0.00	1.52	3.49
MISSING	0.44	1.17	1.24	0.56	0.00	2.14	5.55
TOTAL	16.34	37.81	28.70	13.06	0.22	3.87	100.00

Table 2. Percentage Frequency Distribution of the difference between P-values based on 19- and 75-foot wind speeds (mph) and P-values based on 19- and 150-foot wind speeds (mph) for each hour of the day. January 1961 – December 1964. Number of observations ———35,064. (Taken from Moses and Bognar (1967)).

	19&75—FOOT P-VALUE MINUS 19&150—FOOT P-VALUE												
HOUR	≤ −.5	−.4	−.3	−.2	−.1	0.0	.1	.2	.3	.4	≥ .5	MISSING	TOTAL
1	0.01	0.01	0.01	0.11	1.66	1.75	0.18	0.03	0.03	0.03	0.06	0.29	4.17
2	0.01	0.01	0.01	0.12	1.61	1.80	0.19	0.05	0.03	0.03	0.04	0.28	4.17
3	0.02	0.01	0.02	0.11	1.66	1.78	0.16	0.07	0.03	0.03	0.03	0.27	4.17
4	0.01	0.00	0.01	0.09	1.67	1.75	0.19	0.03	0.03	0.04	0.07	0.27	4.17
5	0.02	0.01	0.03	0.11	1.60	1.75	0.15	0.09	0.03	0.04	0.04	0.30	4.17
6	0.01	0.02	0.03	0.16	1.56	1.77	0.15	0.05	0.02	0.03	0.06	0.31	4.17
7	0.03	0.01	0.02	0.17	1.52	1.96	0.14	0.02	0.02	0.01	0.03	0.24	4.17
8	0.01	0.00	0.03	0.13	1.05	2.52	0.17	0.01	0.02	0.01	0.02	0.20	4.17
9	0.01	0.01	0.02	0.05	0.69	2.99	0.19	0.01	0.01	0.01	0.01	0.17	4.17
10	0.00	0.00	0.01	0.04	0.55	3.20	0.18	0.01	0.01	0.01	0.01	0.16	4.17
11	0.00	0.00	0.01	0.03	0.55	3.23	0.17	0.01	0.01	0.00	0.00	0.15	4.17
12	0.00	0.00	0.00	0.03	0.55	3.30	0.12	0.00	0.01	0.00	0.00	0.16	4.17
13	0.00	0.00	0.00	0.03	0.50	3.30	0.16	0.01	0.00	0.01	0.00	0.15	4.17
14	0.01	0.01	0.00	0.03	0.52	3.27	0.16	0.01	0.00	0.01	0.00	0.15	4.17
15	0.00	0.00	0.00	0.03	0.60	3.21	0.14	0.01	0.00	0.00	0.01	0.16	4.17
16	0.00	0.00	0.01	0.04	0.85	2.98	0.11	0.01	0.01	0.01	0.01	0.16	4.17
17	0.00	0.00	0.00	0.05	1.08	2.66	0.10	0.03	0.01	0.01	0.02	0.22	4.17
18	0.01	0.00	0.01	0.04	1.44	2.20	0.15	0.03	0.02	0.02	0.03	0.23	4.17
19	0.00	0.01	0.01	0.05	1.48	2.03	0.15	0.05	0.04	0.03	0.05	0.28	4.17
20	0.02	0.00	0.01	0.07	1.63	1.87	0.14	0.06	0.01	0.03	0.05	0.27	4.17
21	0.01	0.01	0.02	0.07	1.68	1.77	0.18	0.07	0.01	0.04	0.05	0.27	4.17
22	0.02	0.01	0.02	0.09	1.69	1.74	0.16	0.06	0.01	0.03	0.06	0.27	4.17
23	0.01	0.00	0.01	0.09	1.65	1.79	0.13	0.03	0.05	0.02	0.05	0.33	4.17
24	0.02	0.01	0.01	0.11	1.69	1.73	0.15	0.06	0.03	0.03	0.04	0.29	4.17
TOTAL	0.23	0.12	0.30	1.81	29.49	56.34	3.72	0.80	0.46	0.45	0.75	5.55	100.00

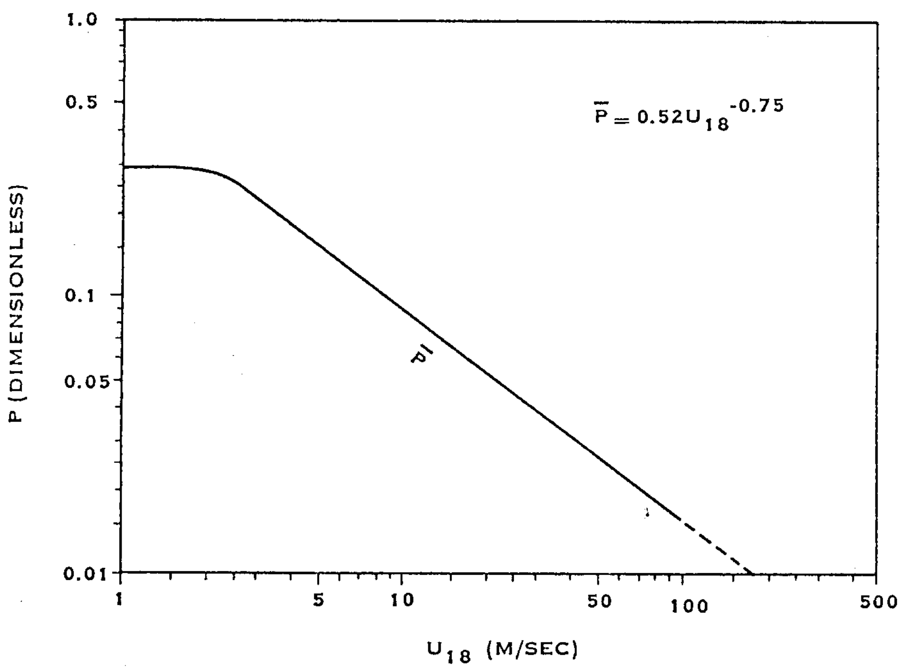

Figure 1. Mean value of P (determined by least-squares analysis of each peak wind profile between 18- and 150- meters) as a function of the peak wind at the 18-meter level. Fichtl (1970)

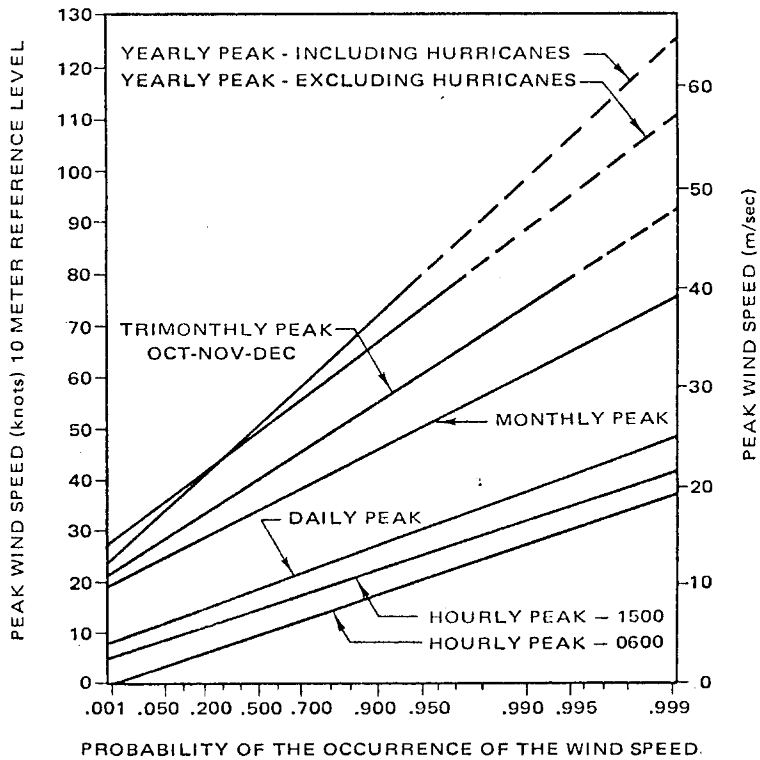

Figure 2. Fisher - Tippett distribution collated to peak wind speed samples at Cape Kennedy, Florida in October. Fichtl (1970) extended by Crutcher (1975)

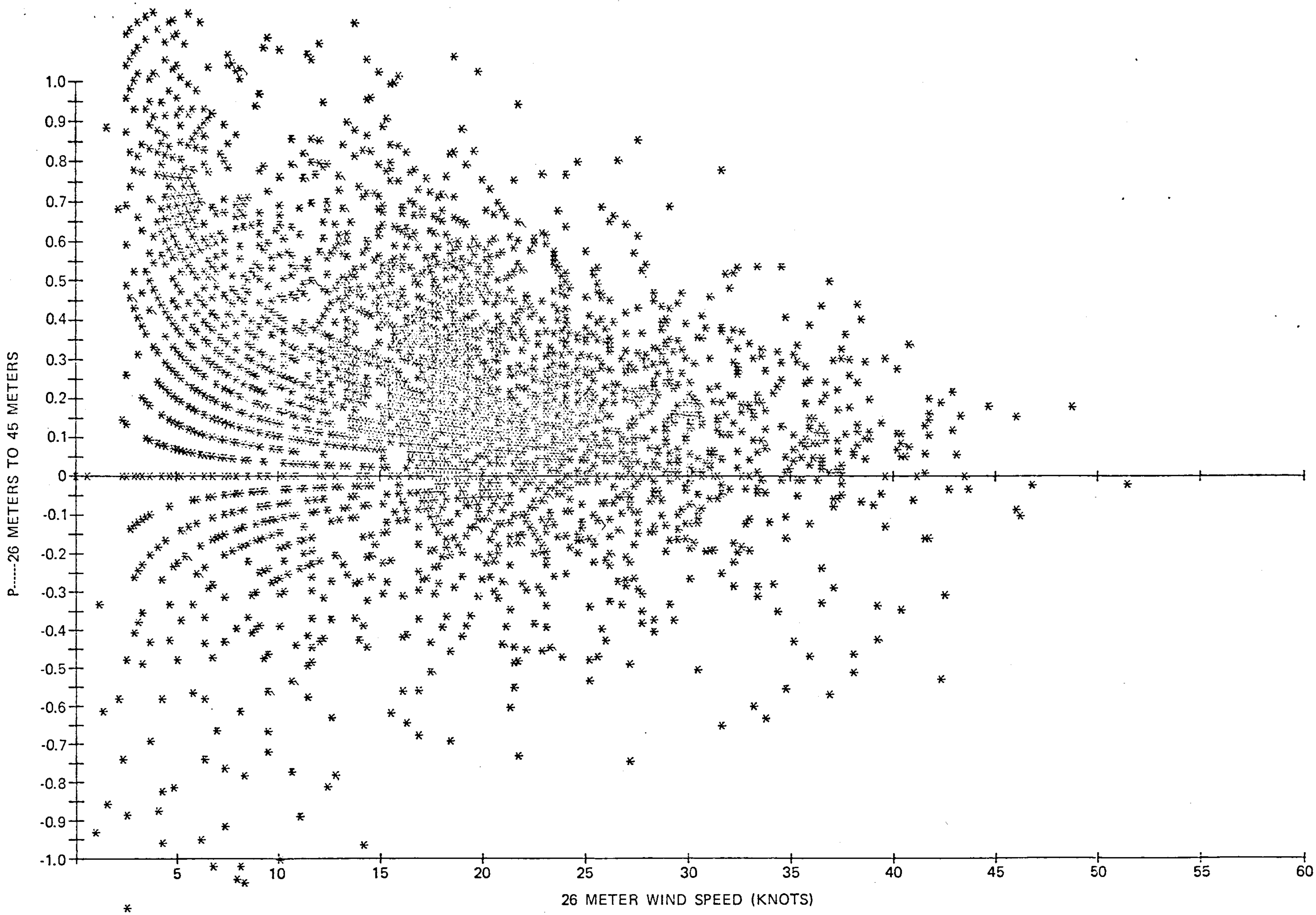

FIGURE 3. VARIATION OF P (26M AND 45M LEVELS) WITH WIND SPEED (KNOTS) AT THE 26M LEVEL FOR 10 THUNDERSTORM RELATED EPISODES IN 1971 AND 1972 AT OKLAHOMA CITY, OK. SET CONTAINS ~3700 OBSERVATIONS MADE AT 10-SECOND INTERVALS.

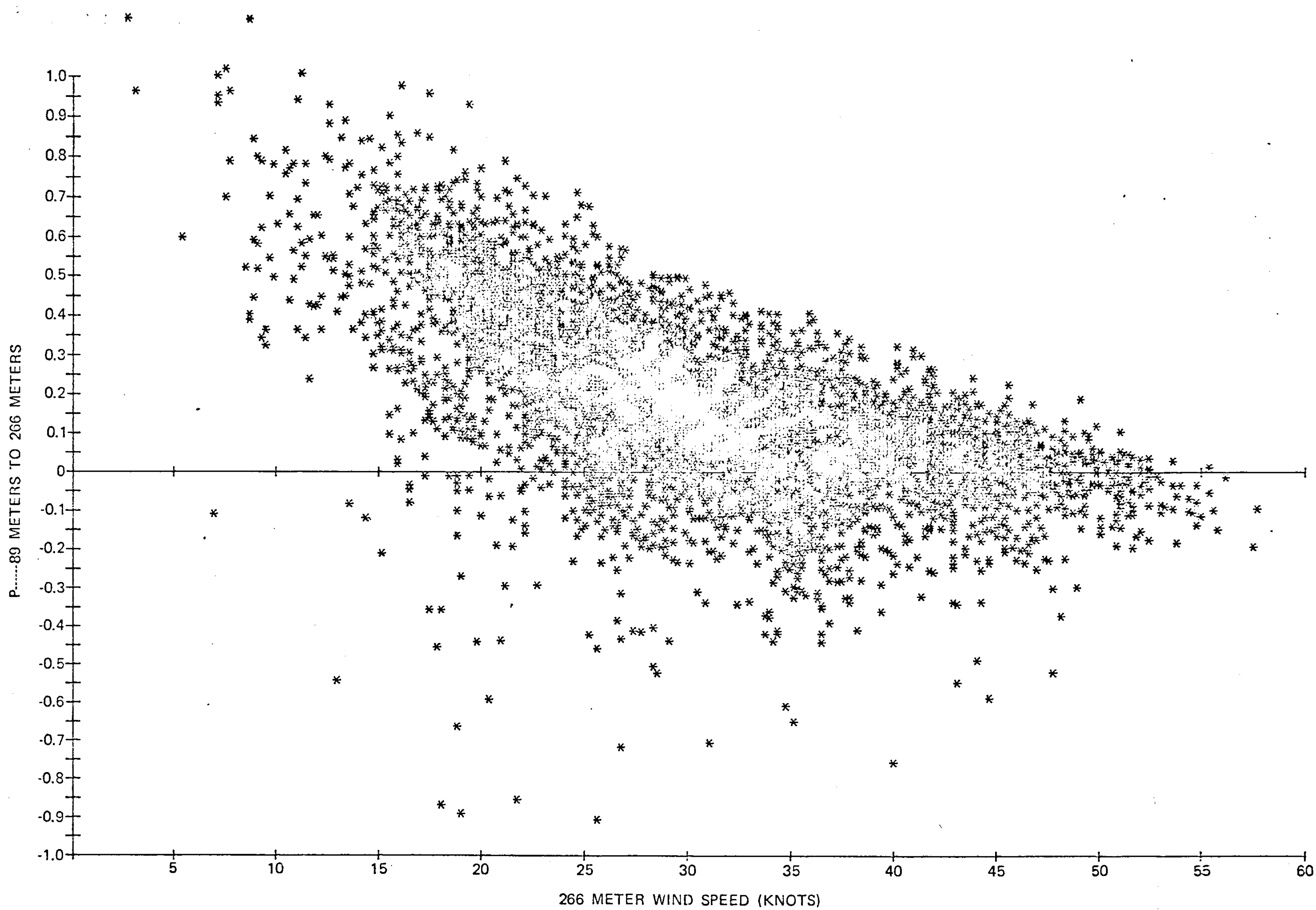

FIGURE 4. VARIATION OF P (89M AND 266M LEVELS) WITH WIND SPEED (KNOTS) AT THE 89M LEVEL FOR 10 THUNDERSTORM RELATED EPISODES IN 1973, 1974 AND 1975 AT OKLAHOMA CITY, OK. SET CONTAINS ~5300 OBSERVATIONS MADE AT 10-SECOND INTERVALS.

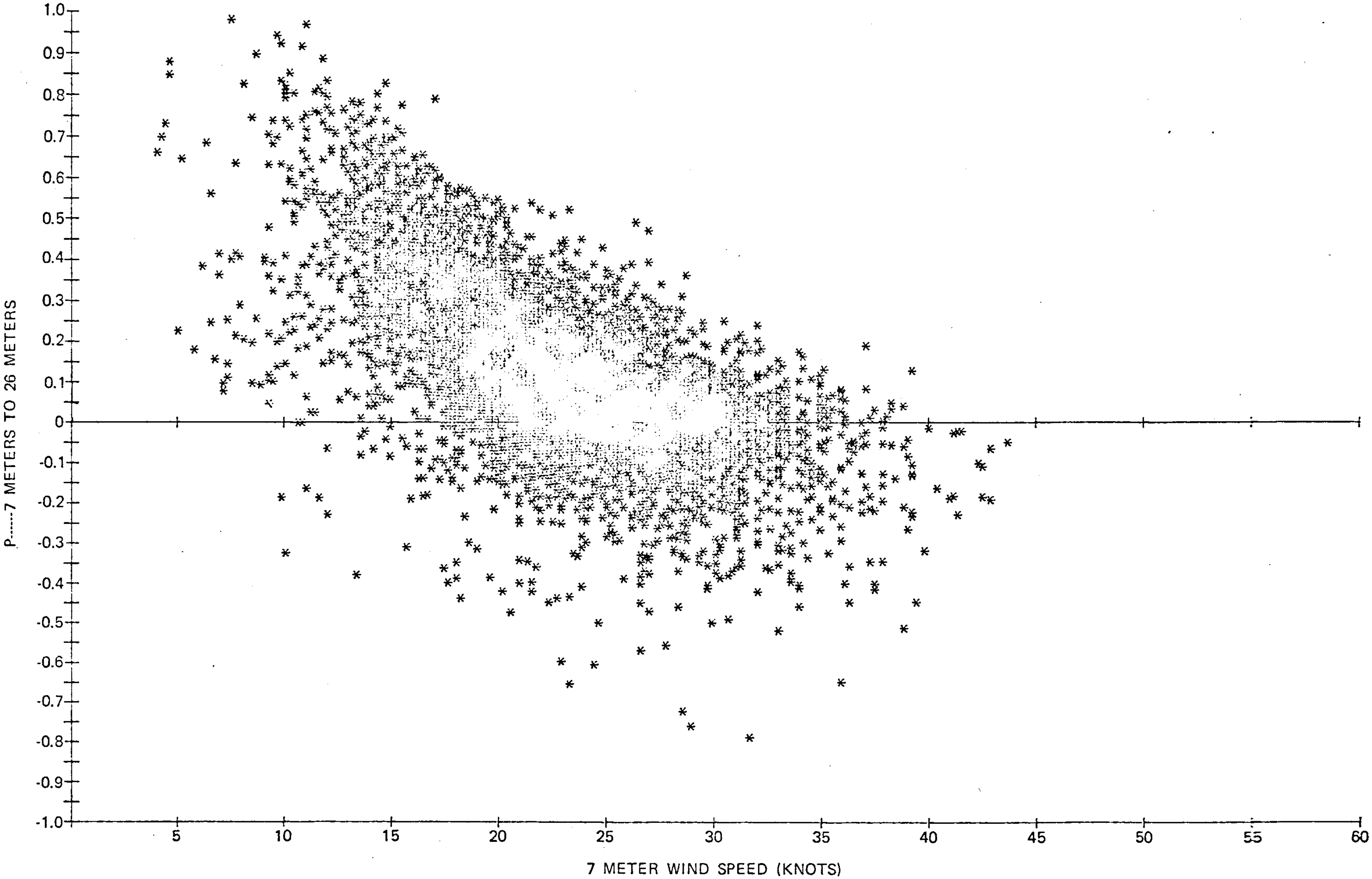

FIGURE 5. VARIATION OF P (7M AND 26M LEVELS) WITH WIND SPEED (KNOTS) AT THE 7M LEVEL FOR TWO SEVERE EXTRA-TROPICAL CYCLONE EPISODES IN MARCH 1977 AT OKLAHOMA CITY, OK. SET CONTAINS ~5100 OBSERVATIONS MADE AT 10-SECOND INTERVALS.

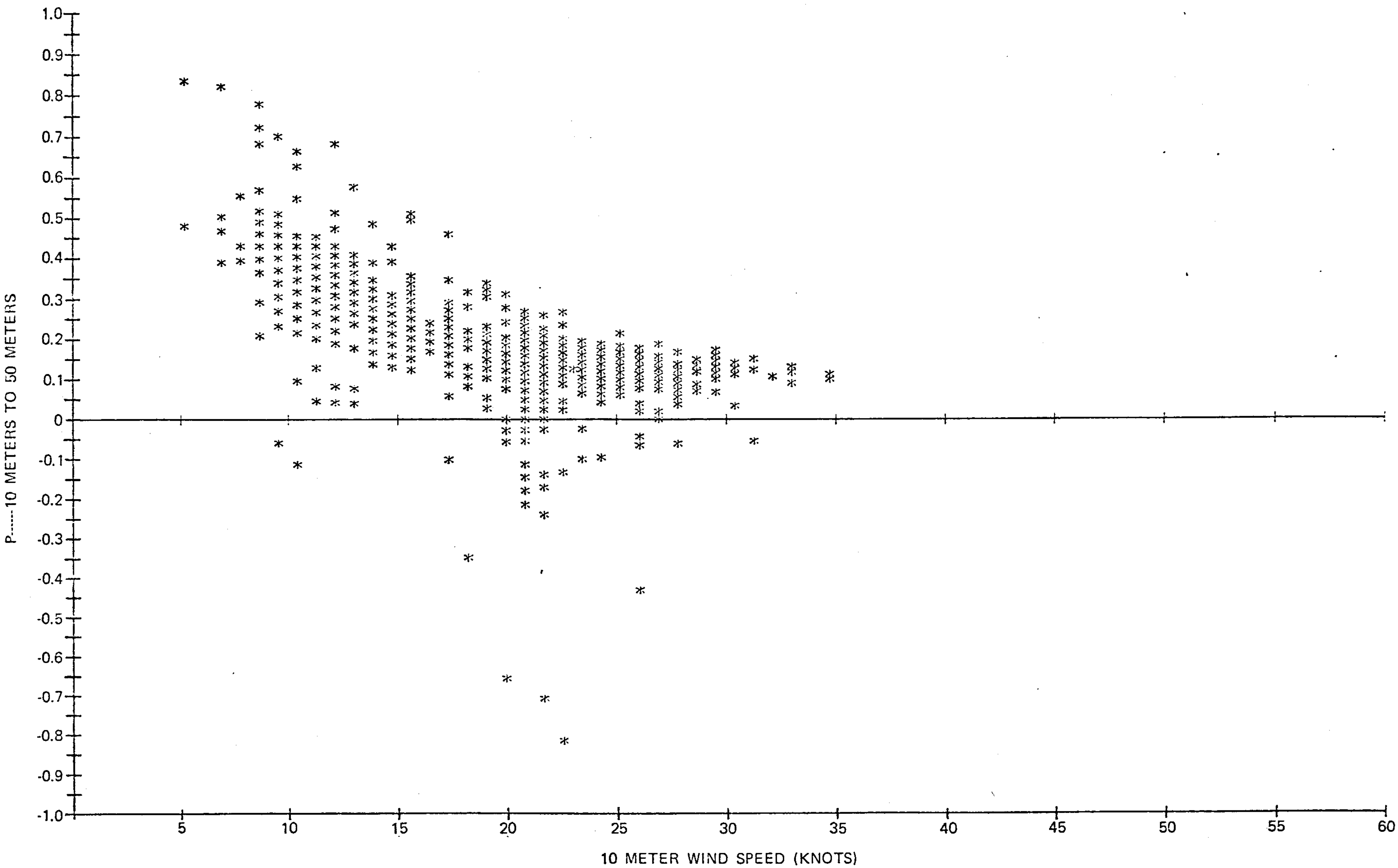

FIGURE 6. VARIATION OF P (10M and 50M LEVELS) WITH WIND SPEED (KNOTS) AT THE 10M LEVEL FOR 32 HIGH WIND SPEED EPISODES IN 1975 AND 1976 AT DUNN CENTER, ND. SET CONTAINS ~900 OBSERVATIONS OF 30 MINUTE MEAN WINDS.